Effects of Red Light on Growth, Photosynthesis and Food Reserves in *Curcuma alismatifolia* Gagnep

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Abstract

The effects of red light on carbohydrate content in *Curcuma alismatifolia* Gagnep were studied. Plants grown under two artificial light sources i.e. T1) red light fluorescent lamp (Philips TLD 36W/15; 632-660 nm) and T2) cool daylight source (Philips TLD 36W/865; 405-812 nm) compared with growing under natural light (T3). In T1 and T2, temperature was controlled at 27±2^{o}C, 70-80% RH and 60 µmol m^{-2} s^{-1} PAR of light intensity. Each plant were supply with 100 ml of nutrient solution comprised of 200 mg N, 50 mg P, 65 mg Ca, 20 mg Mg, 0.22 mg B, 0.54 mg Mn, 0.26 mg Zn, 0.04 mg Mo and 0.45 mg Fe per liter, three times a week. The results showed that plant height, number of leaves per plant, number of plants per cluster, number of new rhizomes per cluster and number of storage roots per rhizome plant grown under red light condition of were not significantly different from cool day light. However, values of other parameters were decreased in red light treatment. The growth of plant grown under red light and cool day light conditions were less than under natural light. Moreover, *C. alismatifolia* grown under red light, the starch, total nonstructural carbohydrate (TNC), reducing sugar (RS) and total nitrogen under red light condition was less than the other. Except, total soluble sugar (TSS) of new rhizome and storage root was not significantly different with cool day light condition.

Keywords: *Curcurma alismatifolia* Gagnep, plant nutrition, rhizome quality

Introduction

In 2004, Thailand exported about 1,233,581 rhizomes of *C. alismatifolia* to USA. Australia, Ecuador, Israel, Italy, Japan, Korea, Nepal, the Netherlands, Pakistan and Singapore (Department of Agricultural and Extension, 2005). They are suitable for growing as summer flowering potted plants anywhere in the United States. Often, rhizomes are harvested from December to April in Thailand and shipped to the United States for forcing (Kuehny, 2001). In general of *C. alismatifolia*, the total growing period is 7 to 8 months, and flowering takes place for 2 to 3 months. When flowering ceases, the aerial structures dry and the rhizome become dormant (Phongpreecha, 1997). The climatic conditions are average temperate at 27-28^{o}C, 12-13 h of daytime duration and 70-80% RH. Then plant becomes dormancy in November to December when the approximately temperature is

30/16°C (max/min), 10 h of sunshine duration and 65-70% RH. (Apavatjrut et al, 1999; Burch et al., 1987). Manipulation of plant material to satisfy dormancy requires investigation on the individual plant requirements. It appears that controlling growth, development and flowering in geophytic plants is dependent on reserve accumulation, mobilization and redistribution (Phongpreecha, 1997). C. alismatifolia is herbaceous perennial with short fleshy rhizome and storage roots or tuberous roots. (Burch et al., 1987). The rhizome is a major source of water and carbohydrates. (Wannagrairot, 1997). *C. alismatifolia* have develop swollen roots to store water and reserve food for plant growth (Phongpreecha, 1997). Therefore, the knowledge of factors affecting these mechanisms would be useful with development of cultural techniques that control shoot emergence and flowering. Among environmental condition, light is one of the limiting factors and affects growth and development of plants. Light quality shows and important role in morphogenesis and photosynthesis (Kim et al., 2003). Red light is important for the development of the photosynthetic apparatus of plants and may increase starch accumulation in several plants species by inhibiting the translocation of photosynthates out of leaves (Saebo et al., 1995). Nowadays, new technology developed coloured shade nets which blue, green, red or infra-red light is absorbed through the nets which consequently has a specific effect on plant growth (Armstrong, 2007). This new cultural technique should be also benefit for *C. alismatifolia* production. After import curcuma rhizomes from Thailand, growers in foreign countries usually produced curcuma plants in glass-house using supplement artificial light. Not only curcuma production in foreign countries, off-season production of *C. alismatifolia* in Thailand also used artificial light source for night-break technique to improve quality of flowers and rhizome. However, little information is available on how red light influences the growth, photosynthesis and food reserves of *C. alismatifolia*. This research was aimed to investigate the effect of red light on plant growth and food reserve in rhizome and storage roots. The basic data from this experiment could be useful for developing new cultural technique of colored nets using this plant.

Materials and Methods

Plant Materials and Conditions

Rhizomes of *Curcuma alismatifolia* cv. Chiang Mai Pink with diameter 2.5 cm with 4-5 storage roots were grown in plastic bags containing sand: rice husk: rice husk charcoal at the ratio of 1:1:1. After shoot and root emerged (about two weeks after planting: WAP), plant were transferred to growth chambers. There were three different light sources ie, 1) red light fluorescent lamp (Philips TLD 36W/15; 632-660 nm wavelength), 2) cool daylight source (Philips TLD 36W/865; 405-812 nm wavelength) and 3) the natural light source. The condition of the growth room was set up at 27±2°C, 70-80% RH and 60 µmol m^{-2} s^{-1} PAR of light intensity. Each plant were supply with 100 mL of nutrient solution comprised of 200 mg N, 50 mg P, 200 mg K, 65 mg Ca, 20 mg Mg, 0.22 mg B, 0.54 mg Mn, 0.26 mg Zn, 0.04 mg Mo and 0.45 mg Fe per liter at three times a week. The growth and development of plants in term of plant height (cm), diameter of pseudo-stem (cm), number of leaves per plants, number of new rhizomes per cluster and number of storage roots per rhizome were measured. Photosynthetic rate (Pn) was measured using leaf chamber analyzed (Model Type LCA-4, Halma group Co.Ltd.) and chlorophyll fluorescence (*Fv/Fm*) was measured using plant efficiency analyzer (Model PEA. Hansatech Intrument, UK) at the uppermost of leaf from shoot apex at 3, 4 and 5 weeks after planting. Total non-structural carbohydrates (TNC) and reducing sugar (RS) were determined by Nelson's method (A.O.A.C., 1990). Total nitrogen (N) was determined by modified Kjeldahl method (Ohyama et al., 1985, 1991). Fifty mg of freeze-dried sample was extracted with 80% ethanol. The supernatant was analysed for total soluble sugar concentration. The precipitated fraction was analyzed for starch. Twenty-five mg of residue was extracted with 8.14 N $HClO_4$ to determine the starch concentration by the anthrone method (JSPN, 1990). Total soluble sugars were determined using the phenol-H_2SO_4 method. The methods were previously described in detail elsewhere (Ohyama et al., 1985, 1986).

The experimental design was completely randomized design with 10 replications (pots) per treatment for growth parameters and 4 replications per treatment for food reserves. Data of parameters were analyzed as a completely randomized design using the MINITAB Statistical Package.

Results and Discussion

Plant Growth and Development

Height of plant grown under red light condition (92.30 cm) was not significantly different compared with cool day light (97.70 cm) and plant under both conditions were higher than natural light (42.40 cm) (Table 1). The cause of abnormal elongation of plants under red and cool day light was due to low light intensity (60 µmol m^{-2} s^{-1} PAR) of these conditions compared with control in T3 (9000 µmol m^{-2} s^{-1} PAR), rather than affects of light quality. Although in some plant such as primrose plants, blue light stimulated growth of leaf and elongation of leaf petiole whereas the effect of red light was the opposite (Michalczuk and Goszczynska, 2002).

On the other hand, pseudo-stem diameter, number of plants per clusters and number of leaves per plant were less than natural light treatment (Table 1). Decreasing growth under red light and cool day light should be occurred from lower light intensity (60 µmol m^{-2} s^{-1} PAR) compared with natural light (9000 µmol m^{-2} s^{-1} PAR). The different of light intensity was affective to photosynthesis and metabolism in plant. In moderate light intensity, plant generally bears longer internodes. In *Panicum maximum*, higher light intensity stimulated growth, tillerling and yield (Deinum et al., 1996).

C. alismatifolia grown under red light and cool day light condition began to early flower at 4 weeks after planting (4 WAP) (Figure 1A,C). Plants under red light reached to dormancy stage at 19 WAP earlier than plants grown under cool day light and natural light (23 and 25 WAP, respectively). In potted primrose plants (*Primula acaulis* 'Corona Scarlet') illuminated with red light during the entire experiment caused a decrease in flower number (Michalczuk and Goszczynska, 2002).

Under red light treatment, the number of new rhizomes per cluster was 1.00 rhizomes and it was not significantly different from under cool day light (2.00 rhizomes per cluster). Under natural light treatment, the new rhizome was 3.67 rhizomes per cluster (Table 2). Lower formation of new rhizomes under red light and cool day light treatments may be due to insufficient of light intensity (60 µmol m^{-2} s^{-1} PAR) compared with natural light (9,000 µmol m^{-2} s^{-1} PAR) brought about poorly growth and development. The low light intensity decreased number of shoots and tuber formation of *Alstroemeria* (Noordegraaf, 1981). The diameter of new rhizome under red light condition (0.92 cm) was significantly different from the other treatments. The fresh and dry weights of new rhizome under red light were less than plants under cool day light and natural light treatments (Table 2).

The number of storage roots per rhizome under red light condition and cool day light were significantly different from under natural light (1.67, 3.33 and 7.67 storage roots per rhizome, respectively). Diameter of storage root under red light was lower than the others (Table 2). The fresh and dry weight of storage roots under red light condition (13.73 and 0.91 g) were significantly lower than plants under cool day light (15.92 and 2.07 g) and natural light (17.55 and 2.20 g).

Table 1 Growth of *C. alismatifolia* grown under different light sources at 11 WAP[1/].

Light sources	Height (cm)	Diameter of pseudo-stem (cm)	No. of plants per cluster	No. of leaves per plant	Leaves area (cm^2)
Cool day light	97.70^{a}	1.11^{b}	1.90^{b}	3.30^{b}	116^{b}
Red light	92.30^{a}	0.80^{c}	1.40^{b}	3.30^{b}	93^{b}
Natural light	42.40^{b}	1.36^{a}	2.90^{a}	4.10^{a}	162^{a}

[1/] Mean within the same column followed by different letter are significant different between treatment at P<0.05.

Table 2 Effect of different light sources on yield and qualities of new rhizomes and storage roots of *C. alismatifolia* at harvest[1/].

New rhizome				
Light source	Number of new rhizomes per cluster	Diameter of new rhizome (cm)	Weight of new rhizome (g)	
			Fresh	Dry
Cool day light	2.00[b1/]	1.94[a]	5.43[b]	1.32[a]
Red light	1.00[b]	0.92[b]	3.23[b]	0.66[b]
Natural light	3.67[a]	2.30[a]	6.48[a]	1.66[a]
Storage root				
Light source	Number of storage roots per rhizome	Diameter of storage root (cm)	Weight of storage root (g)	
			Fresh	Dry
Cool day light	3.33[b1/]	1.30[a]	15.92[b]	2.07[b]
Red light	1.67[b]	0.90[b]	13.73[c]	0.91[c]
Natural light	7.67[a]	1.60[a]	17.55[a]	2.20[a]

[1/] Mean within the same column followed by different letter are significant different between treatment at $P<0.05$.

Photosynthetic Rate and Chlorophyll Fluorescent

Photosynthetic rate was measured by measurement of the volume of carbondioxide by LCA-4 instrument at 10.00 am at 5 WAP. Photosynthetic rate of plant under red light was 14.95 µmol m^{-2} s^{-1} and it was not significantly different from plant under cool day light (15.05 µmol m^{-2} s^{-1}), indicating that different wave length but the same light intensity between cool day light and red light did not affect photosynthetic rate. On the other hand, photosynthetic rate of plant grown under natural light treatment was 27.56 µmol m^{-2} s^{-1} which it was significantly higher than the other treatments (Table 3), due to higher light intensity and leaves area (Table 1). The general competence in photosynthetic rate of plant depended on type of plant and environment of plant growth (Jone and Lazenby, 1988). In this experiment, leaves areas of plant under natural light condition was higher than plants under red light. The leaves area was important to photosynthesis. It was found that the larger leaves area give higher photosynthesis (Nivut, 1992).

The chlorophyll fluorescent of *C. alismatifolia* leaves grown under light condition at 5 WAP shown in Table 4. The *Fv/Fm* ratio indicated the effect of outside factors to chlorophyll efficiency and stress of plant (Flagella et al., 1994). Chlorophyll fluorescence values of *C. alismatifolia* grown under red light was 0.81 and it was not significantly different from plants grown under cool day light (0.84). However, values of both conditions were higher than plants grown under natural light (0.72) (Table 4). Generally, the *Fv/Fm* ratio was found in a remarkably narrow range (0.83±0.004) among leaves of many different species, environmental stress the affect PSII efficiency lead to a characteristic decrease in *Fv/Fm* (Krause and Weis, 1991). In this experiment, the *Fv/Fm* of plants grown under red light and cool day light were not decreased compared with natural light condition indicating that plants under these conditions did not stress.

Table 3 Photosynthetic rate of plants grown under different light sources at 5 WAP[1/].

Light source	Photosynthetic rate (µmol m^{-2} s^{-1})
Cool day light	15.05[b]
Red light	14.95[b]
Natural light	27.56[a]

[1/] Mean within the same column followed by different letter are significant different between treatment at $P<0.05$.

Table 4 Characteristics of chlorophyll in plants grown under different light sources at 5 WAP[1/].

Light source	Chlorophyll fluorescence (*Fv/Fm*)	Total chlorophyll	Chlorophyll a	Chlorophyll b
Cool day light	0.84[a1/]	0.88[a]	0.69[a]	0.19[a]
Red light	0.81[a]	0.63[c]	0.49[c]	0.14[c]
Natural light	0.72[b]	0.78[a]	0.61[a]	0.17[b]

[1/] Mean within the same column followed by different letter are significant different between treatment at $P<0.05$.

Although, the total chlorophyll, chlorophyll A and chlorophyll B of plants grown under red light were less than the other treatments (Table 4), but high correlation was not obtained between the chlorophyll content and the photosynthesis rate (Marini, 1986). Chlorophyll content and chloroplast positions associated with environmental factors such as intensity of incident light (Hendry and Price, 1993; Kagawa et al., 2001). Furthermore, lower chlorophyll content of plant grown under red light also found in leaves of tobacco (HongZhi et al., 1998). Chlorophyll B in plant was synthesized from chlorophyll A and its increase followed by increasing of chlorophyll A (Khampiranonh, 1983). The data of this experiment showed that reduction of chlorophyll B under red light also related with the decrease of chlorophyll A content (Table 4).

Although, total chlorophyll content of plant grown under cool day light was not different from natural light condition but its photosynthetic rate was reduced (15.05 µmol m^{-2} s^{-1}) compared with natural light treatment (27.56 µmol m^{-2} s^{-1}). This result indicated that the photosynthetic rate is independent of the chlorophyll content. Lichtenthaler et al. (1981) also reported that the photosynthetic CO_2-fixation capacity of sun leaves is independent of the chlorophyll content of leaf area.

Food Reserve Concentration in Plants

Total nonstructural carbohydrate (TNC) of new rhizome and storage roots under red light condition were 151.35 and 122.05 mg g^{-1} DW, respectively and they were less than the other conditions (Table 5). The starch concentration in new rhizome and storage roots under red light (93.68 and 162.94 mg g^{-1} DW, respectively) were significantly lower than cool day light (183.43 and 222.45 mg g^{-1} DW, respectively) and natural light (336.88 and 326.91 mg g^{-1} DW, respectively). Because photosynthetic rate did not significantly different between cool day light and red light (Table 5), therefore, decreasing of TNC and starch affected by red light may be involved to enzyme activity for starch degradation.

Total soluble sugar (TSS) of new rhizome and storage roots under red light was not significantly different with cool day light condition. But, those concentrations under both conditions were less than natural light condition (Table 6). It indicated that different wave length conditions did not affect TSS. Lichtenthaler et al. (1981) reported that soluble carbohydrates in leaf of many plants (*Aesculus hippocastanum*, *Tilia cordata, Fagus sylvatica, Triticum aestivum and Zea mays*) are lower under low light intensity. Reducing sugar (RS) concentration in new rhizome and storage roots of plants under red light condition (16.44 and 25.81 mg-glucose g^{-1} DW, respectively) were significantly lower than those of cool day light (24.11 and 53.36 mg-glucose g^{-1} DW, respectively) and those of natural light (26.47 and 66.96 mg-glucose g^{-1} DW, respectively). Total soluble sugar and reducing sugar in plants indicated the mobilization of assimilated to storage organ. It has been considered that the increase of assimilates in the storage tissue might act as this signal for stimulating storage organ development (Thomas and Vince-Prue, 1993). In tobacco, red light increased reduced sugar content compared with blue light (HongZhi et al., 1998).

Total nitrogen of new rhizome and storage roots under red light condition were less than the other treatments (Table 5). The total nitrogen of new rhizome under red light, cool day light and natural light were 25.84, 36.70 and 59.34 mg-N g^{-1} DW, respectively. Nitrogen concentration in new rhizome of all treatments were higher than in storage roots. Ruamrungsri et al. (2001) reported that rhizome of

Table 5 Total nonstructural carbohydrate (TNC), starch and total nitrogen in new rhizome and storage roots of *C. alismatifolia* under different light source treatments at harvest[1/].

Organ	Light source	TNC (mg-glucose g^{-1} DW)	Starch (mg g^{-1} DW)	Total N (mg-N/ g^{-1} DW)
New rhizomes	Cool day light	277.35[a]	183.43[b]	36.70[b]
	Red light	151.35[b]	93.68[c]	25.84[c]
	Natural light	283.52[a]	336.88[a]	59.34[a]
Storage roots	Cool day light	245.57[b]	222.45[b]	12.63[b]
	Red light	122.05[c]	162.94[c]	10.17[c]
	Natural light	268.65[a]	326.91[a]	15.70[a]

[1/] Mean within the same column followed by different letter are significant different between treatment at P<0.05.

Table 6 Reducing sugar (RS) and total soluble sugar (TSS) in new rhizome and storage roots of *C. alismatifolia* under different light source treatments at harvest[1/].

Organ	Light source	TSS (mg g^{-1} DW)	RS (mg-glucose g^{-1} DW)
New rhizomes	Cool day light	44.04[b]	24.11[a1/]
	Red light	43.34[b]	16.44[b]
	Natural light	74.65[a]	26.47[a]
Storage roots	Cool day light	51.77[b]	53.36[b]
	Red light	47.37[b]	25.81[c]
	Natural light	94.05[a]	66.96[a]

[1/] Mean within the same column followed by different letter are significant different between treatment at P<0.05.

C. alismatifolia is the principal organ for N storage and the storage root is the major organ for carbohydrate storage, such as starch and soluble sugar. Increasing of nitrogen compound in storage roots caused by N application and these compound may play an important role in the storage of N in the storage roots (Ohtake et al., 2006). In tobacco, red light decreased nitrogen metabolism compared with blue light (HongZhi et al., 1998).

Conclusions

C. alismatifolia. grown under red and cool day lights with 60 µmol m^{-2} s^{-1} PAR light intensity caused abnormal elongation of plants. These conditions accelerated flowering, decreased photosynthetic rate and chlorophyll contents but increased chlorophyll fluorescence. Illumination of plants during the entire experiment with red or cool day light at 60 µmol m^{-2} s^{-1} PAR decreased yield and quality of rhizomes. However, the experiments of light intensity and illumination periods using red light should be done to clarify the effect of red light on growth and development of this plant.

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